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## **Validity and Reliability of Firefighting Simulation Test Performance**

**Running title:** Validity of a Firefighting Simulation Test

**Objective** To assess the validity and reliability of a firefighting simulation test (FFST).

**Methods** Sixty-nine operational firefighters completed a best-effort FFST on one occasion and twenty-two participants completed a further FFST. All participants completed a maximal treadmill test to determine cardiorespiratory fitness (VO<sub>2</sub>max).

**Results** Time to complete the FFST demonstrated a strong inverse relationship with VO<sub>2</sub>max ( $r = -0.73$ ), although the prediction error was high. Reliability of the FFST was high ( $r = 0.84$ ,  $p = 0.01$ ), demonstrating a coefficient of variation of 4.5%.

**Conclusions** The FFST demonstrated reasonable validity as a surrogate assessment of cardiorespiratory fitness for firefighting. The FFST also demonstrated good reliability. Given the apparent magnitude of the prediction error, the FFST would be best used as a training tool, rather than as a primary means of assessing cardiorespiratory fitness for firefighting.

**Key Words:** Firefighting, performance test, validity and reliability, physical fitness,

## **Introduction**

Physically demanding public safety occupations (e.g. police, fire and ambulance) require employees to possess the physical and physiological attributes to perform their duties safely and effectively, preferably without experiencing excessive physical strain. Without a minimum level of physical fitness, particularly cardiorespiratory fitness, workers may be subjected to overexertion, which can increase the risk of injury to the employee and may also affect public safety<sup>1-3</sup>. With the improved understanding of the risks to employees in these physical occupations, in particular from excessive cardiovascular strain<sup>4-6</sup>, there is a recognition that employers have a duty of care to administer regular fitness assessments to ensure that their employees maintain appropriate minimum levels of physical fitness for safe and effective work<sup>7-8</sup>.

Physical fitness tests in demanding occupations typically take the form of either criterion (i.e. job simulation) or surrogate (i.e. predictive) tests. Criterion tests are either discrete job tasks or simulations, whereas surrogate tests measure components of fitness that are associated with performance on job-related tasks<sup>9</sup>. In an occupational setting, the type of test used will often depend on practical factors such as resource availability, financial constraints and/or safety considerations. However, since the aim of the fitness test is primarily to determine potential operational performance and, ultimately, suitability for employment, it is essential that the psychometric properties of the tests demonstrate an acceptable level of validity and reliability. While criterion tests naturally have content or ‘face’ validity, performances on these tests can be more markedly affected by factors such as weather conditions (where job simulations are performed outside) and test familiarisation than predictive tests<sup>10</sup>. Surrogate or predictive fitness tests (e.g. the Harvard step test) tend to be less complex, and can often

be more easily administered in controlled conditions (i.e. a fitness or occupational health facility), which typically increases safety and test-retest reliability<sup>11</sup>. However, predictive tests inevitably contain prediction error which, when applied to a workforce, can introduce bias and call into question their validity and occupational relevance when compared to criterion tests that more closely resemble the job. Identifying valid and reliable fitness tests for physically demanding jobs is important to help identify workers that can undertake their role effectively thus improving employee and public safety.

Several studies have investigated the association between a variety of fitness indices with simulated firefighting performance. Expectedly, cardiorespiratory fitness exhibits strong associations with tasks of longer duration, where little to no correlation is observed with individual, short duration (< 30 seconds) firefighting tasks<sup>12-13</sup>. Weak to moderate (but significant) correlations have been observed with combined task simulations lasting between 5 and 10 minutes in U.S ( $r = -0.38$ )<sup>13</sup> and Norwegian ( $r = -0.53$ ) firefighters<sup>14</sup>. Cardiorespiratory fitness exhibits the strongest associations with firefighting simulations lasting approximately 10 minutes ( $r^2 = 0.57$ )<sup>15</sup> or longer ( $r = -0.72$ )<sup>16</sup>, supporting the notion that cardiorespiratory fitness is an important determinant of task performance during sustained tasks.

Studies investigating the reliability of timed task simulations have, however, received comparatively little attention. One study investigated the variability in task performance during a Canadian Forces firefighter work simulation test<sup>10</sup>. Participants completed six best-effort attempts of a standardised firefighting simulation with 24 to 48 hours between trials. Even with thorough orientation procedures and controlled test conditions, a continual improvement in performance on the occupational task was observed. While the test-retest correlations between sequential trials were high ( $r =$

0.957 to  $r = 0.988$ ), significant variations in mean task performance were evident between all trials<sup>10</sup>.

In a series of recent studies, we identified and established job-related simulations involving the critical and most physically demanding firefighting tasks<sup>17</sup>. We also quantified the metabolic cost of these simulations and proposed a minimum cardiorespiratory fitness standard for operational performance<sup>18</sup>. Treadmill-based tests of minimum cardiorespiratory fitness are now used to assess the occupational fitness of UK Fire and Rescue Service personnel. However, it is unknown whether a simulation, composed of these firefighting tasks can be used as a valid and reliable criterion test of operational fitness. This study was performed to: (a) assess the validity of a firefighting simulation test (FFST) to estimate maximal cardiorespiratory fitness ( $\text{VO}_{2\text{max}}$ ) and; (b) establish the test-retest reliability of the FFST.

## **Methods**

### *Participants*

Sixty-nine (64 male, 5 female) operational firefighters from seven UK Fire and Rescue Services (FRS) volunteered for this study and gave written consent to participate following written and verbal explanation of the test procedures. All study participants were trained operational personnel and considered medically fit for firefighting duties. The study was approved by the University of Bath Research Ethics Approval Committee for Health (REACH Reference number: EP 12/13 6).

### *Study design*

Previous studies have determined the critical and most physically demanding tasks undertaken by UK firefighters and identified standardised simulations for each of

these tasks<sup>17</sup>. From this work a criterion firefighting simulation test (FFST) was developed by combining three of these tasks. These were selected based on the critical and physically demanding nature of the tasks and the ability to be easily replicated on a standard fire service training ground. After a familiarisation procedure, participants were required to complete this firefighting simulation in the quickest possible time along with a maximal treadmill test to determine their maximal oxygen uptake (VO<sub>2</sub>max).

### *Firefighting Simulation Test (FFST)*

The firefighting simulation consisted of ‘equipment carry’, ‘casualty evacuation’ and ‘hose run’ tasks<sup>17</sup> and are described in detail in Table 1.

*[INSERT TABLE 1 ABOUT HERE]*

The tasks were selected to be completed in the order described (equipment carry, casualty evacuation, hose run) such that physical demand (reported previously)<sup>18</sup> was incremental (i.e. least demanding to most demanding). Prior to undertaking the firefighting simulation, each firefighter was given full instruction of the task protocol and completed 2-3 attempts in the two weeks prior to the start of the testing procedure.

On the day of assessment, participants were instructed to avoid strenuous exercise and to eat and drink as normal. Participants completed the FFST in full firefighting ensemble (i.e. tunic, leggings, boots, flash-hood, helmet, gloves (total mass ~8.2 kg)), whilst carrying, but not breathing on, a self-contained breathing apparatus (SCBA) set (total mass 12.0 kg) during the casualty evacuation component of the simulation. Participants had to don and doff the SCBA set prior to and following the casualty evacuation elements of the task. Participants were asked to complete the FFST in the fastest time possible whilst adhering to standard operating procedures, manual

handling and safety regulations. The time taken to complete each of the three stages/tasks of the FSST was recorded, as well as perceived exertion<sup>19</sup> at the end of the FFST.

#### *Test retest reliability*

At least 7-days later, a sub-sample of 22 participants (20 male, 2 female) completed a second best-effort attempt of the FFST to examine test-retest reliability. Both best-effort attempts were performed at the same fire station and at approximately the same time of day using the same equipment and pre-test conditions.

#### *Cardiorespiratory fitness test*

Participants also performed a maximal running protocol (in standard gym kit: running shoes, shorts and t-shirt) on a motorised treadmill (Life Fitness, Cambridge, UK) to determine their maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ). This was conducted at the participants' designated fire stations in on-site gym facilities. Prior to the exercise test, anthropometric data (i.e. body mass, height, estimated body fat [BodyStat 1500, Bodystat Ltd., UK]) were collected. For the exercise test a 2-3 minute self-selected warm up was completed prior to commencing the test protocol which consisted of completing 4 (or 5 if required), 3-minute stages of walking or running at a constant speed with a 3% increase in gradient at the end of each stage until volitional exhaustion. Participants wore a portable breath-by-breath gas analyser (K4-B2, Cosmed, Italy). Peak  $\text{VO}_{2\text{max}}$  was established by calculating the mean of the highest minute of continuous oxygen consumption.

### *Statistical analysis*

Statistical analysis was undertaken using SPSS version 22 (IBM, New York, USA). Mean anthropometric and performance (VO<sub>2</sub> max and task time) data were compared between male and female firefighters using independent t-tests. A Pearson's correlation coefficient was used to determine the relationship between the FFST time and VO<sub>2</sub> max. Shapiro-Wilk's tests were conducted to assess for normality of data distribution. Standard error of estimate (SEE) statistics were calculated to determine the size of the mean error from the estimation plot. Agreement between the FFST and VO<sub>2</sub> max scores was also assessed by determining the 95% limits of agreement (95% LoA) as previously described by Bland and Altman<sup>20</sup>. Test-retest reliability data were examined using Pearson's correlation coefficients between FFST attempts and a paired t-test was used to identify differences between mean performance times. Statistical significance was set at  $p \leq 0.05$ . The variability between attempts was assessed using coefficient of variation (CV).

### **Results**

The mean (and standard deviation) firefighter physical and performance characteristics are presented in Table 2. All participants completed all tasks successfully/correctly and with “very hard” to “maximal” perceived exertion/effort (a rating of perceived exertion of  $\geq 17$  (Borg, 1982).

*[INSERT TABLE 2 ABOUT HERE]*

The male firefighters in this study were 8-years older ( $p = 0.04$ ), 20-kg heavier ( $p < 0.01$ ) and had a body mass index 5.4 kg m<sup>-2</sup> greater ( $p = 0.01$ ) than their female



colleagues (Table 2). Interestingly, there were no significant differences between males and females in height ( $p = 0.19$ ) or estimated body fat percentage ( $p = 0.12$ ), despite the fact that males were 3 cm taller and 4 percentage points leaner than the females. The mean time to complete the firefighting simulation for all firefighters was 608 ( $\pm 90$ ) seconds, with male firefighters ( $600 \pm 77$  seconds) completing the task significantly quicker ( $p < 0.01$ ) than the female firefighters ( $706 \pm 57$  seconds).

Figure 1 shows the relationship between FFST task completion time (in seconds) and measured  $\text{VO}_2$  max (maximal treadmill test). The time to complete the FFST was highly inversely correlated with cardiorespiratory fitness ( $r = -0.73$ ,  $p = 0.01$ ). The SEE was equivalent to 55 seconds on the FFST.

*[INSERT FIGURE 1 ABOUT HERE]*

Data describing the physical characteristics of participants used in the reliability analysis are described in Table 3. The relationship between the FFST performance time trials are presented in Figure 2.

*[INSERT TABLE 3 ABOUT HERE]*

Participants that performed the two reliability trials were, on average, quicker during the second trial ( $595 (\pm 74)$  seconds) compared to the first ( $612 (\pm 83)$  seconds), although this difference was not statistically significant ( $p = 0.09$ ). Test-retest reliability of the FFST was high, revealing a strong relationship between the mean completion time of trial 1 and trial 2 ( $r = 0.84$ ,  $p = 0.01$ ). The coefficient of variation between the two tests was calculated to be 4.5%, equivalent to 27 seconds.

*[INSERT FIGURE 2 HERE]*

## **Discussion**

This study was undertaken to investigate the validity of a best-effort performance on a firefighting simulation test (FFST) to estimate the minimal maximal cardio-respiratory fitness ( $\text{VO}_2\text{max}$ ) required for operational firefighting and to determine the test-retest reliability. The time taken to complete the FFST demonstrated a strong inverse correlation with  $\text{VO}_2\text{max}$  demonstrating that performance on the FFST is strongly determined by cardiorespiratory fitness. Furthermore, the FFST simulation demonstrate a high degree of reliability ( $r = 0.842$ ). However, the prediction error associated with the simulation (SEE of  $6.13 \text{ ml.kg}^{-1}.\text{min}^{-1}$ ), the 95% limits of agreement with  $\text{VO}_2 \text{ max}$  ( $16.2 \text{ ml.kg}^{-1}.\text{min}^{-1}$ ) and the test-retest coefficient of variation (4.5%) suggest it may not be suitably accurate to supersede already widely-used predictive treadmill tests and may not be considered an appropriate criterion fitness test if used in isolation.

Whilst previous studies have identified equivocal findings in the relationship between firefighting task performance and cardiorespiratory fitness, test protocols used have varied widely<sup>16</sup>. Studies investigating individual tasks or short-duration simulations have reported little to no association with cardio-respiratory fitness<sup>12-13</sup>. However, work involving firefighting simulations lasting more than a few minutes have reported stronger and statistically significant associations with overall task performance<sup>13-14</sup>, with the strongest correlations in firefighting simulations lasting greater than 10 minutes<sup>15-16</sup>. Interestingly, a number of these studies have also reported that when isolated from the complete simulation, specific tasks involving stair climbing<sup>13</sup> and casualty rescue<sup>14</sup> have elicited stronger correlations compared with the overall task performance. This supports the notion that the specific type or nature of the

physical task(s) involved in the simulation, may be as important as the duration of the task itself, in terms of determining the reliance on and strength of association with cardiorespiratory fitness. In support of this, stair climbing and casualty rescue tasks have been identified as being some of the most aerobically demanding tasks in firefighting<sup>18, 21-22</sup>. These factors suggest that the combination of several different tasks, and subsequently, the total duration of the simulation in the current study may have facilitated the validity as an operationally relevant test of cardiorespiratory fitness.

Other methodological differences may also affect the relationship between the fitness variable and firefighting task performance. Two of the longest duration simulations described in the literature, used specifically designed firefighter applicant<sup>15</sup> or incumbent<sup>16</sup> simulation tests, where the former separated firefighting activities with periods of (walking) recovery<sup>15</sup>. The nature of urgency by which the firefighting tasks are completed may also be of importance. Participants completing the simulations in the studies described were instructed to complete the tasks, “with no unnecessary waste of time”<sup>14</sup>, “at a steady and rapid pace”<sup>13</sup>, or “as quickly as possible”<sup>12,16</sup>. It is therefore impossible to know whether participants in these studies achieved best-effort performances, which would be more likely to elicit a stronger correlation with maximal cardiorespiratory fitness. In the present study, participants completed the FFST in the fastest possible time without walking or recovery between tasks. Furthermore, upon completion of the FFST, all participants reported an RPE of 17 or more. This represents the most likely reason why the relationship between task completion time and cardiorespiratory fitness in this study was stronger than those associations reported in the wider literature.

Despite the strong relationship between FFST performance and cardiorespiratory fitness observed in this study, only 54% of the total variance in task

time could be explained by cardiorespiratory fitness. Additionally, the SEE of  $6.13 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  equates to 55 seconds on the firefighting simulation. Whilst the SEE of 4.5% is similar to other reported studies<sup>15</sup>, the value of this error in absolute terms indicates that this test may not be suitable to use as a stand-alone test to accurately determine fitness for duty in UK firefighters. The current minimum cardiorespiratory fitness standard for UK firefighters is  $42.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , which would equate to a pass score of 10 minutes and 44 seconds on the FFST. However, the SEE equates to 55 seconds on the simulation test. As such, in isolation, this test may not be suitably accurate to determine whether a firefighter was fit or safe enough to successfully undertake firefighting duties without undue physical strain.

The test-retest reliability of the FFST was strong ( $r = 0.84$ ) and the variability between the two trials was 4.5% or 27.1 seconds, which is similar to other studies involving firefighting simulations<sup>10,16</sup>. Whilst the correlations reported by Boyd et al.<sup>10</sup> were higher ( $r = 0.95 - 0.98$ ) between each consecutive pair of six trials and the variation between trials smaller (2.6%) during the latter part of the study, these tasks were completed 24 to 48 hours apart in an indoor, temperature-controlled facility. This was in contrast to the current study where trials were completed outdoors, one to two weeks apart and where natural variations in the ambient conditions were present, which likely explains the weaker correlations observed.

Considering the work of Boyd et al.<sup>10</sup>, improvements in best-effort times on the FFST may have been achieved where further task familiarisation was possible. However, as this study was conducted using operational firefighters, whilst on-duty, emergency duties and other work commitments made this difficult to achieve. Indeed, due to time restrictions, it was also not possible to collect strength or muscular endurance performance data from the firefighters used in this study. This may have

been useful, allowing the determination of the effects of multiple fitness characteristics on FFST performance, particularly as both strength and muscular endurance have been reported to be important determinants of firefighting performance in specific tasks<sup>23</sup>.

The FFST investigated in this study has been shown to be a reasonably valid and highly reliable test for predicting cardiorespiratory fitness. However, the error terms observed for the validity and reliability raise questions of the efficacy of the test when aiming to apply the minimum fitness standard for UK firefighters<sup>18</sup>. The use of this test in isolation and without prior health and fitness screening may not be suitable to effectively identify firefighters that are above/below the fitness standard and therefore capable of safe and efficient operational firefighting performance. Therefore, this type of test may be better utilised when included within a larger fitness management process to ensure firefighters are at least above a minimum level of cardiorespiratory fitness before undertaking this test. This would minimise the possibility for error and, more importantly, help ensure the safety of the incumbent performing the FFST. Importantly, the FFST can now be used as part of a regular operational firefighter fitness training programme.

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### Figure Legends

Figure 1. Relationship between completion time (seconds) on the firefighting simulation versus VO<sub>2</sub>max ( $n = 69$ ,  $r = -0.734$ ,  $r^2 = 0.539$ ), with line of best fit.

Figure 2. Test-retest reliability: relationship between the first and second attempts at the firefighter simulation test ( $n = 22$ ,  $r = -0.842$ ,  $r^2 = 0.708$ ).